



3 1176 00156 5036

NASACR-159,148

NASA CONTRACTOR REPORT 159148

NASA-CR-159148
19790025046

SUMMARY REPORT

ACCELERATED DEVELOPMENT AND FLIGHT EVALUATION OF ACTIVE CONTROL CONCEPTS FOR SUBSONIC TRANSPORT AIRCRAFT

LOCKHEED-CALIFORNIA COMPANY, BURBANK, CALIFORNIA

CONTRACT NASA-14690

OCTOBER 1979



National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23665
AC 804 827-3966

LIBRARY COPY

*LANGLEY RESEARCH CENTER
LIBRARY
HAMPTON, VIRGINIA*

1. REPORT NO. NASA CR-159148		2. GOVERNMENT ACCESSION NO.		3. RECIPIENT'S CATALOG NO.	
4. TITLE AND SUBTITLE SUMMARY REPORT - ACCELERATED DEVELOPMENT AND FLIGHT EVALUATION OF ACTIVE CONTROLS CONCEPTS FOR SUBSONIC TRANSPORT AIRCRAFT				5. REPORT DATE October 1979	
				6. PERFORMING ORG CODE	
7. AUTHOR(S)				8. PERFORMING ORG REPORT NO. LR 29111	
9. PERFORMING ORGANIZATION NAME AND ADDRESS LOCKHEED-CALIFORNIA COMPANY P.O. BOX 551 BURBANK, CALIFORNIA 91520				10. WORK UNIT NO.	
				11. CONTRACT OR GRANT NO. NAS1-14690	
12. SPONSORING AGENCY NAME AND ADDRESS National Aeronautics and Space Administration Langley Research Center Hampton, Virginia 23665				13. TYPE OF REPORT AND PERIOD COVERED Contractor Report Summary	
				14. SPONSORING AGENCY CODE	
15. SUPPLEMENTARY NOTES Summary Report					
16. ABSTRACT Summarizes the successful development and flight test of active load alleviation/extended span for the L-1011 wide-body transport aircraft, plus piloted simulation work leading to use of active stability augmentation with a small tail and aft center of gravity. The extended span showed the expected cruise drag reduction of 3%. The small tail is expected to reduce cruise drag by another 3%, and eventual use of more aft center of gravity with active stability augmentation will provide further fuel savings. The active load alleviation functions included maneuver load control (MLC) and elastic mode suppression (EMS), using symmetric motions of the outboard ailerons to reduce wing bending loads in maneuvers or long-term up- or down-drafts (MLC), and to damp wing bending motions in turbulence (EMS). They also included a gust load alleviation function using the active horizontal tail to provide airplane pitch damping in turbulence. This last function was found unnecessary. The piloted simulation tests evaluated criteria for augmentation-on and augmentation-off flying qualities. Suitability of a simple pitch control law was verified at neutral static margin. The simulation tasks established the basis for follow-on construction and flight testing of a small tail with active stability augmentation.					
17. KEY WORDS (SUGGESTED BY AUTHOR(S)) Active Controls Load Alleviation/Extended Span Relaxed Static Stability Flight Simulation			18. DISTRIBUTION STATEMENT		
19. SECURITY CLASSIF. (OF THIS REPORT) Unclassified		20. SECURITY CLASSIF. (OF THIS PAGE) Unclassified		21. NO. OF PAGES 65	
				22. PRICE*	

N179-33217 #

NASA CONTRACTOR REPORT 159148

SUMMARY REPORT

**ACCELERATED DEVELOPMENT AND FLIGHT
EVALUATION OF ACTIVE CONTROL CONCEPTS
FOR SUBSONIC TRANSPORT AIRCRAFT**

LOCKHEED-CALIFORNIA COMPANY, BURBANK, CALIFORNIA

CONTRACT NASA-14690

OCTOBER 1979



National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23665
AC 804 827-3966

CONTRACT OBJECTIVES

This report covers the application of active controls to a modern wide-body transport, the Lockheed L-1011, for increased aerodynamic efficiency. The term "active controls" is applied to aircraft systems in which controls are moved automatically, independently of the pilot, in response to signals from appropriate sensors. Active controls may be used for flight path control, for load alleviation, and for ride comfort control. This aircraft already contained active controls for flight path management in its Autoland automatic landing system, Reference 1, and for vertical stabilizer design load reduction, Reference 2. These developments were important in setting up some of the basic principles and techniques for active controls in commercial transports: the use of probability-based analyses to maintain a level of safety consistent with past experience (Reference 2), and definition and mechanization of the related redundancy and monitoring requirements (Reference 1).

Building on this base, research was started in 1974 on use of active controls for wing load alleviation and for longitudinal stability augmentation. Although the initial objective of the load alleviation was an increase in gross weight using existing wing structure - an increase of 12 percent was found possible - the rising costs of fuel soon made it apparent that load alleviation could best be used to increase the wing span for improved fuel efficiency. The objective of the stability augmentation studies was drag reduction by use of a smaller horizontal tail and reduced stability margin.

Starting in February 1977, these studies were funded on a cost-sharing basis by NASA's Aircraft Energy Efficiency (ACEE) Program, Reference 3, through the Energy Efficient Transport Element (EET), Reference 4, under Contract NAS1-14690. At that time a breadboard load alleviation system was already under test on the full-scale L-1011 Vehicle Systems Simulator (VSS) at Lockheed's Rye Canyon research facility. This report summarizes the results of the NASA/Lockheed Program.

CONTRACT OBJECTIVES

ACTIVE CONTROLS DEVELOPMENT FOR INCREASED AIRCRAFT ENERGY EFFICIENCY FOR AIRLINE SERVICE

- **LOAD ALLEVIATION FOR INCREASED
ASPECT RATIO**
- **STABILITY AUGMENTATION (RSS) FOR
SMALLER TAIL**

CONTRACT TASKS

The contract tasks involved validating the load alleviation systems on the baseline L-1011; designing, building and flight testing the extended tips with active load alleviation; and performing pilot-in-the-loop simulator testing to develop active stability augmentation. This last task also involves defining criteria for acceptable augmentation-off flying qualities.

CONTRACT TASKS

- **FLIGHT TEST SYSTEMS ON BASELINE L-1011 AIRCRAFT (TASK 1)**
- **BUILD TIP EXTENSIONS AND FLIGHT TEST WITH ACTIVE LOAD ALLEVIATION (TASK 3)**
- **MOVING-BASE SIMULATOR TESTING TO DEVELOP ACTIVE STABILITY AUGMENTATION (TASK 2)**

FUEL SAVINGS OBJECTIVES (NEAR TERM)

A predicted 3 percent fuel saving for the span extension has been validated by flight test. The production version will enter airline service in 1980.

The predicted fuel saving for the small tail is based on a combination of profile drag reduction due to smaller exposed area, improved tail lift-drag ratio due to a more advanced airfoil shape, and a weight saving of 770 kg (1700 lb). The smaller tail will be built and flight tested under follow-on Contract NAS1-15326.

A U.S. fleet of 500 aircraft of this size and incorporating both the load alleviation/extended span and the augmented stability/smaller tail would save about 200,000,000 gallons of fuel per year.

FUEL SAVINGS OBJECTIVES (NEAR TERM)

EXTENDED SPAN — 3% — 1980

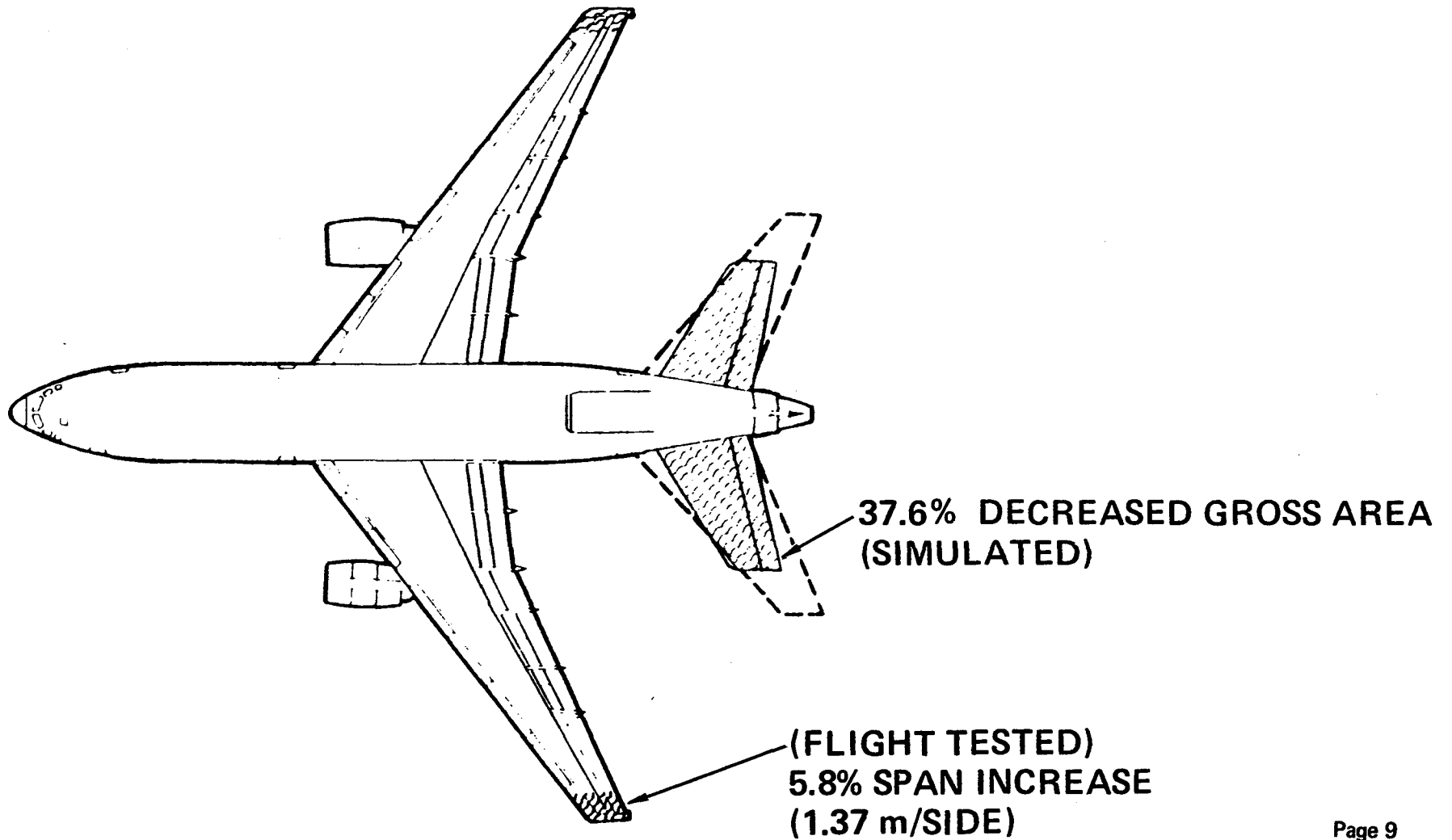
SMALL HORIZONTAL TAIL — 3% — 1983

L-1011 MODIFICATIONS FOR INCREASED ENERGY EFFICIENCY

The L-1011 is a triple-turbofan wide-body transport having the relatively high fuel efficiency and low noise of the high-bypass-ratio fan engine. This figure shows the 5.8% extended span (aspect ratio 7.6) and the 37.6% smaller tail discussed herein.

The baseline wing aspect ratio of 6.95 was proportioned for minimum direct operating costs when fuel costs were about 15 cents per gallon. A relatively low design stress, wide-tread gear and outboard engine location all led to a relatively stiff wing in both bending and torsion, with the result that the outboard ailerons remain effective to the maximum design speed. This characteristic facilitates use of active wing load alleviation which in turn permits the increased span and aspect ratio, with minimum structural impact, appropriate to design for a higher fuel cost level.

L-1011 MODIFICATIONS FOR INCREASED ENERGY EFFICIENCY



L-1011 S/N 1001 ADVANCED TRISTAR WITH EXTENDED SPAN

The span extensions were built and tested in this program. The house airplane, L-1011 S/N 1001, is shown here with the extended span.

L1011 S/N 1001 ADVANCED TRISTAR WITH EXTENDED SPAN



ACTIVE CONTROL FUNCTIONS

The load alleviation functions tested included the noted Maneuver Load Control and Elastic Mode Suppression using symmetric outboard aileron deflections, and Gust (Load) Alleviation using the horizontal stabilizer. These functions, as well as the Augmented Stability function also using the horizontal stabilizer, depend on series servos to move the control surfaces on command from a computer that accepts appropriate sensor signals. A block diagram showing these elements is given on p. 21. Outboard aileron series servos were already contained in L-1011 S/N 1001 and in the L-1011 Vehicle Systems Simulator (p. 25). A breadboard pitch series servo was made up for test purposes in this program.

The load redistribution due to Maneuver Load Control is sketched on p. 19. Elastic Mode Suppression refers to the symmetric aileron function of damping wing motions in the fundamental wing bending frequency range of 1.2 to 2 Hz. Gust Alleviation uses the stabilizer to damp vehicle pitch motions in turbulence. The Augmented Stability function has been found to be well satisfied by similar, more powerful, vehicle pitch damping.

ACTIVE CONTROL FUNCTIONS

- **MANEUVER LOAD CONTROL (MLC) – SYMMETRIC OUTBOARD AILERON**
- **ELASTIC MODE SUPPRESSION (EMS) – SYMMETRIC OUTBOARD AILERON**
- **GUST ALLEVIATION (GA) – HORIZONTAL STABILIZER**
- **AUGMENTED STABILITY (AS) – HORIZONTAL STABILIZER**

ACTIVE CONTROLS – SOME BASIC CRITERIA

The basic requirement of the active controls development was that there be no degradation of safety; furthermore, that the level of safety be maintained while accommodating the airlines' need to be able to dispatch scheduled flights, on limited occasions, with one of the redundant channels inoperative. As previously mentioned, the use of probability based analyses to maintain a level of safety consistent with past experience has been established by Reference 2, and the definition of the related system redundancy and monitoring requirements has been described by Reference 1.

ACTIVE CONTROLS – SOME BASIC CRITERIA

- **NO DEGRADATION OF SAFETY**
- **NONDISPATCH CRITICAL, ONE-CHANNEL INOPERATIVE**

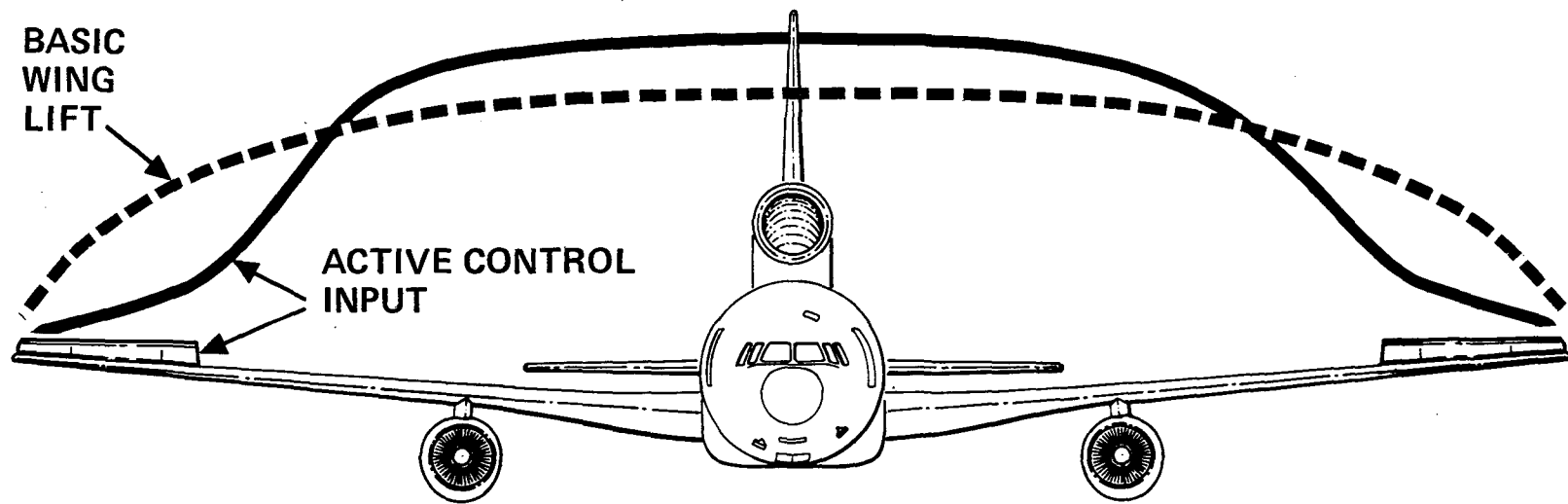
LOAD ALLEVIATION

TASKS 1 AND 3

LOAD REDISTRIBUTION WITH ACTIVE CONTROLS

The primary load alleviation function, Maneuver Load Control, is shown here. The ailerons are faired in level flight, permitting the most efficient span loading, as indicated by the basic elliptic wing lift distribution. In maneuvers, however, the ailerons move to reduce the lift in the outboard regions, keeping the design bending moments on the basic wing no higher than before the span extensions were added. This action allows the low cruise drag of the longer wing with the low weight of a shorter wing.

LOAD REDISTRIBUTION WITH ACTIVE CONTROLS – MANEUVERS

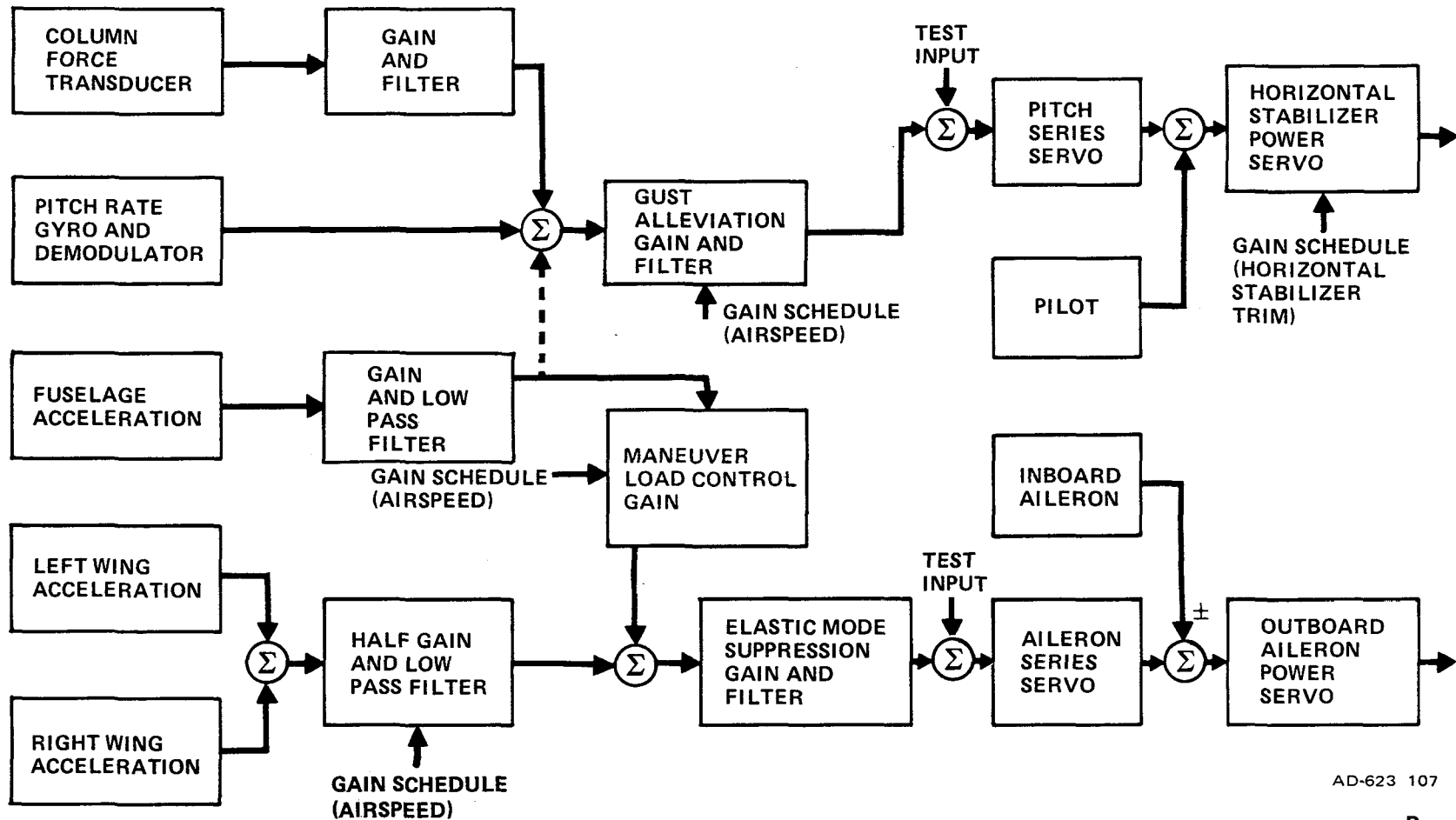


L-1011 MLC/EMS/GA SYSTEM BLOCK DIAGRAM

The MLC, EMS and GA functions were implemented as shown in this block diagram. The fuselage acceleration signal was used for both stabilizer (GA) and aileron (MLC) functions in the baseline tests. It was deleted from the stabilizer (GA) function for the Task 3 extended-span tests.

Note the test input points where step and sinusoidal inputs could be superimposed on the normal functions for open-and closed-loop testing.

L-1011 MLC/EMS/GA SYSTEM BLOCK DIAGRAM



AD-623 107

LABORATORY TESTS

In-house development of the breadboard active controls computer and series servos took place in the Flight Controls laboratory, part of Lockheed's Rye Canyon research facility. The full-scale L-1011 Vehicle Systems Simulator (VSS), p. 25, is a part of that laboratory. Basic control and servo system tests are conducted here. Flight conditions are simulated by tying the VSS in with the Visual Flight Simulator (VFS), using an L-1011 cab and pilot controls with capability for fixed-base or moving-base simulation.

After completion of the baseline flight tests, the systems were returned to the laboratory for updating to the control laws for extended span. Stabilizer series servo modifications were also accomplished.

Finally, a Collins breadboard digital computer was adapted and tested here, under Lockheed funding, to replace the analog computer for the later portions of the contract flight test work, including the gust response testing.

LABORATORY TESTS

SERVOS, ACTUATORS AND COMPUTER

LINEARITY, AMPLITUDE EFFECTS

HYSTERESIS

MINIMUM INCREMENT CONTROL

FREQUENCY RESPONSE (BODE PLOTS)

SIMULATED AIRCRAFT RESPONSES – VSS/VFS

STEP CONTROL INPUTS – OPEN AND CLOSED LOOP

TURBULENCE INPUTS – OPEN AND CLOSED LOOP

FAILURE MODES – CLOSED LOOP

VEHICLE SYSTEMS SIMULATOR (VSS)

The VSS is an exact geometric layout of all of the L-1011 systems including the flight controls, all four hydraulic systems, pumps, landing gear, electrical supply, etc. Principal structural elastic effects are simulated. The view shown is looking aft from the pilot controls cab.. The simulated wings stretch aft to left and right. Some of the leading-edge slats are visible. The simulated fuselage section is over the hydraulic center, and was used to help minimize noise from the hydraulic systems. The four stabilizer power actuators, the actual stabilizer center section and dynamically simulated stabilizer surfaces are contained in or extend from the tower-like structure in the rear.



VEHICLE SYSTEMS SIMULATOR (VSS)

B10-147 274210

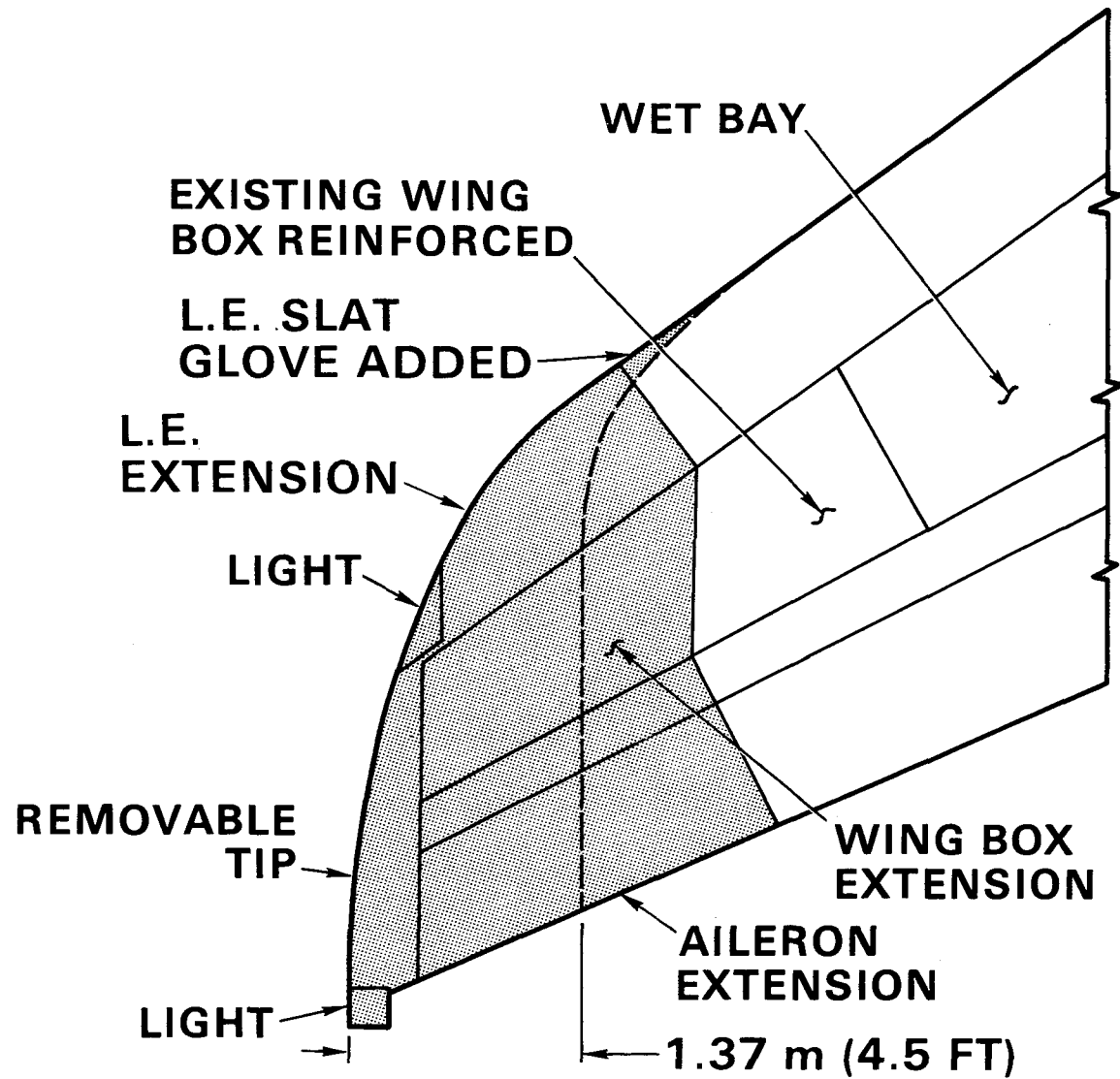
Page 25

STRUCTURAL MODIFICATIONS EXTENDED TIP

While the baseline flight tests were being conducted, the tip extension was designed and fabricated. The 1.37m (4.5 ft) extensions increased the aspect ratio 10 percent. They reduce the cruise drag by 3 percent. The chart indicates the new tip shape and the modification work involved. The new tip shape was selected to be non-stalling and did not require leading-edge slats or ice protection. Two new hinges were added for the aileron extension. The production version will also incorporate a third damper for the extended aileron.

The extensions were similar in mass to the production values of 249 kg (550 lb) per ship; i.e. 31.5 kg/m^2 (6.5 psf). In production, the wing structural modifications inboard of the extensions add a mass of 46 kg (102 lb) per ship.

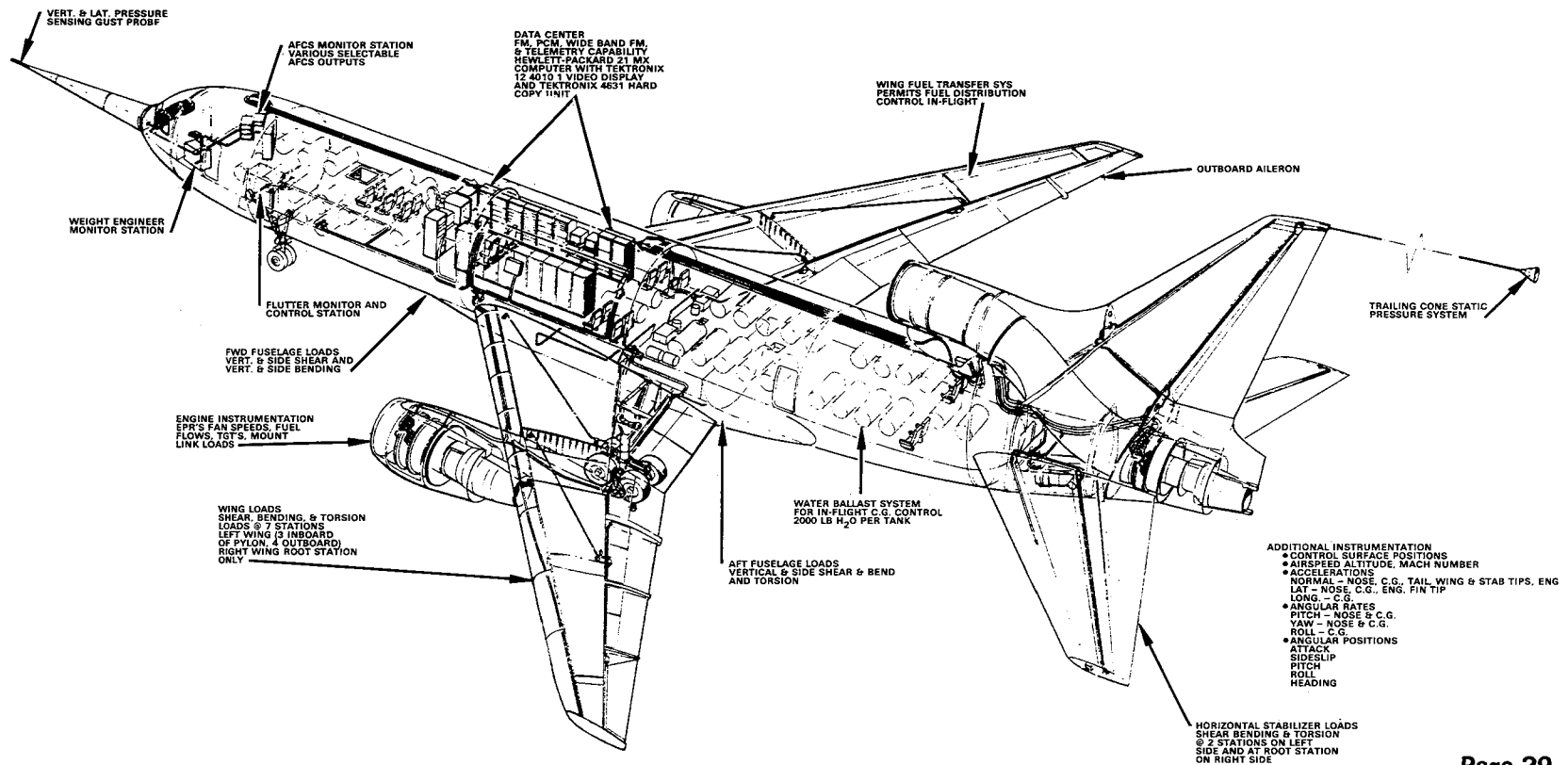
STRUCTURAL MODIFICATIONS



S/N 1001 TEST PROVISIONS

The flight test program was conducted using L-1011-1 serial number 1001. This is one of several airplanes used in the basic L-1011-1 development and certification flight testing and has been retained by Lockheed for continuing flight test use. It was the primary airplane for structural flight testing, including loads measurements and flight flutter testing. Its instrumentation includes extensive strain-gage instrumentation calibrated to read shears, bending moments, and torsions at various locations in the wing, fuselage, and empennage, as well as instrumentation giving control surface positions, accelerations at various locations, airspeed, altitude, etc. A gust boom and probe, previously used in conjunction with gust-load measurements made in 1971, were used on the present program to measure the effects on gust loads of the active system.

S/N 1001 TEST PROVISIONS



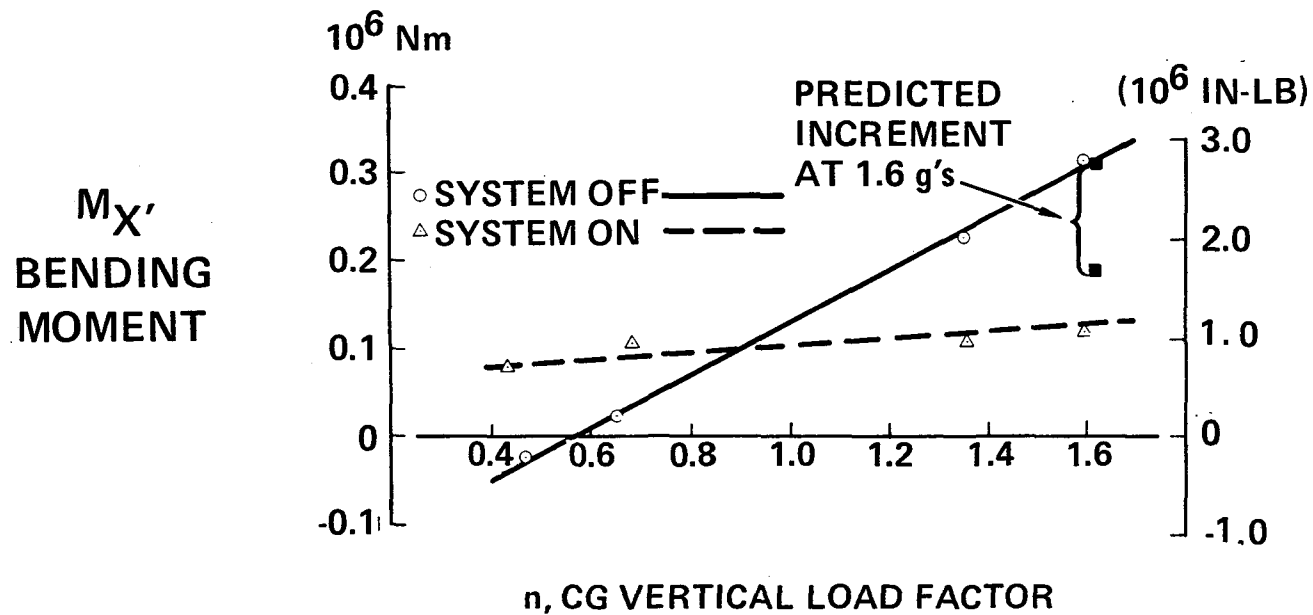
MANEUVER LOADS – ACS EFFECT AT 71 PERCENT SEMISPAN

Maneuver load control is a primary function of the active control system. Here is a typical test result for a cruise case with extended span. The load factor variation was obtained in a pushover, pullup maneuver, or "rollercoaster." The bending moment and vertical shear were decreased, and the torsion moments were increased by the active controls. The increments at 1.6g were all somewhat greater than predicted, because the aileron effectiveness was greater than predicted.

The increased torsion moments (next page) are reflected in the design of the wing with active controls, and account for a small part of the 46 kg (102 lb) per ship added wing structure weight, inboard of the tip extensions, in production.

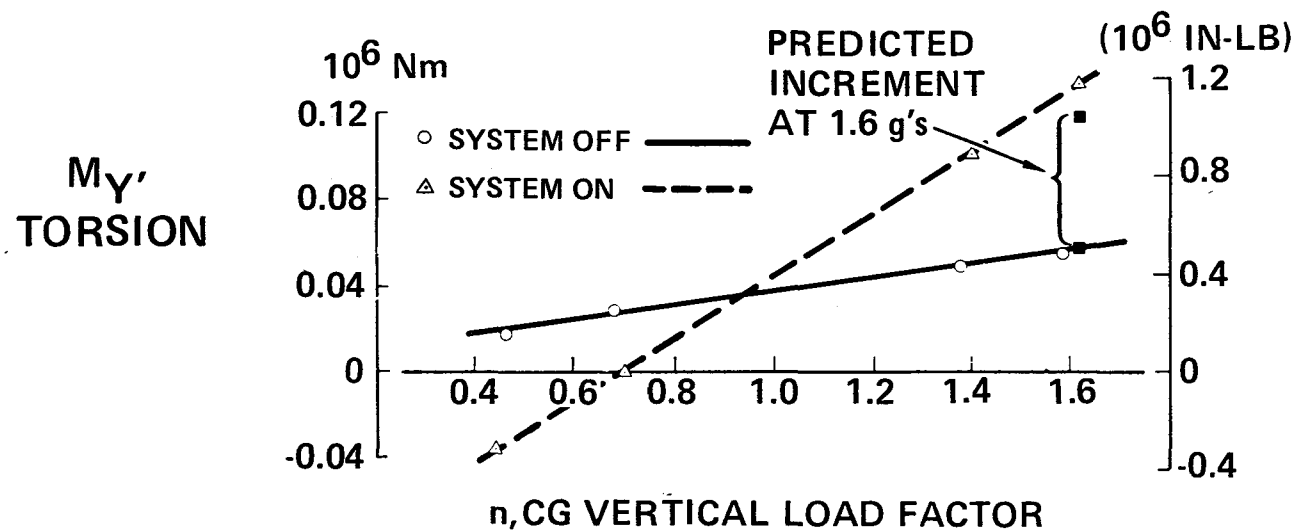
MANEUVER LOADS-ACS EFFECT AT 71% SEMISPAN

EXTENDED SPAN TESTS
 $M = 0.80$, $V = 345$ KEAS



MANEUVER LOADS - ACS EFFECT AT 71% SEMISPAN (CONT)

EXTENDED SPAN TESTS
M = 0.80, V = 345 KEAS

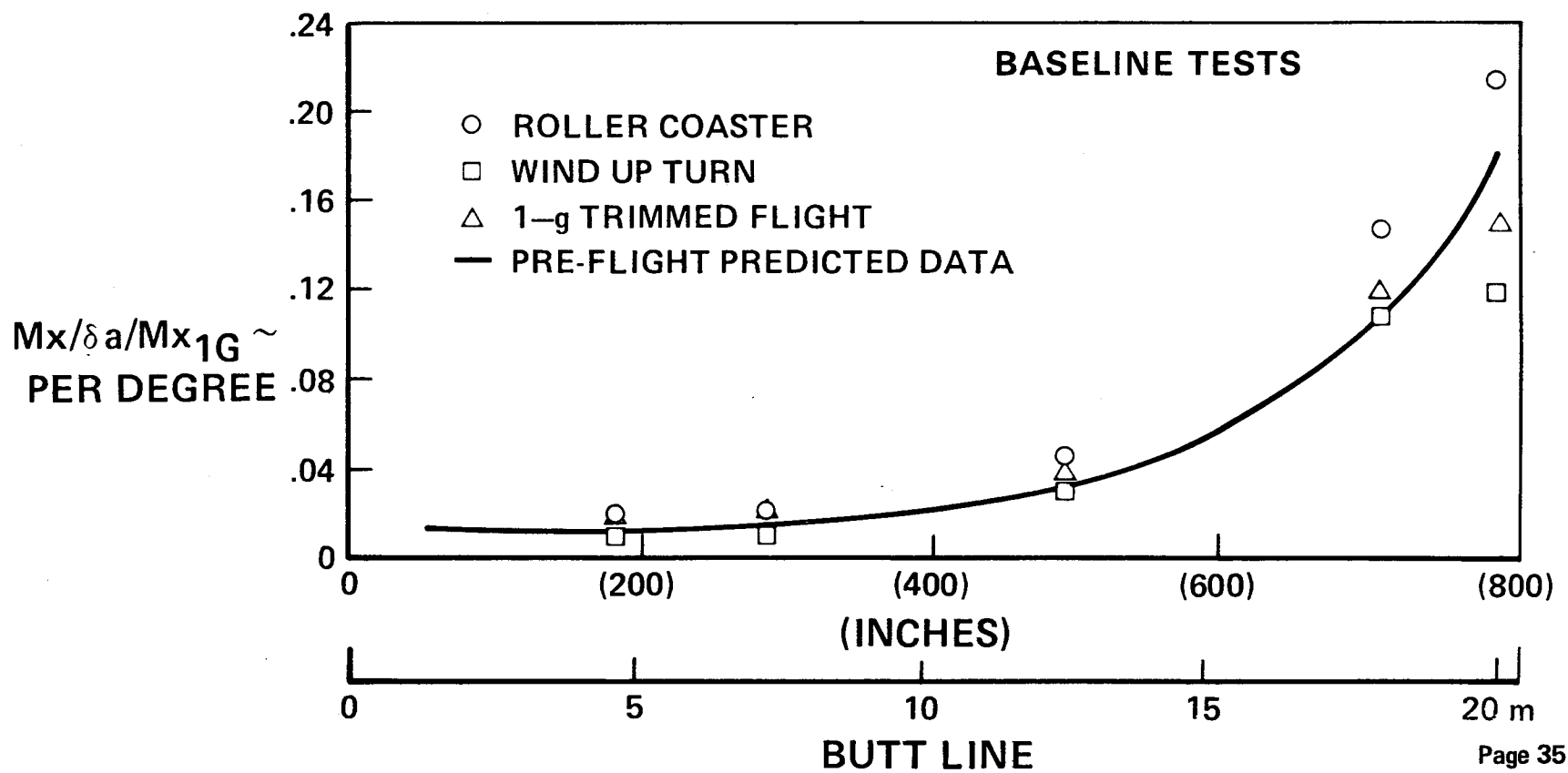


RELATIVE BENDING MOMENT

The ratio of the unit aileron-induced bending moment to the 1-g bending moment (i.e., M_x/δ_a $\div M_x(1-g)$) vs wing spanwise location shows that the change in relative bending moment due to a unit aileron deflection was large at the tip and decreased to less than 2 percent per degree at the wing root. The prediction forms a good fairing of the test data. These data were taken in the baseline configuration during cruise flight.

Similar good agreement of test and analysis was found in aircraft dynamic response tests and flights in turbulence.

RELATIVE BENDING MOMENT



QUESTIONS RESOLVED

This and the following two summary figures take a broad view in accordance with the intent of the ACEE program — to advance technology for implementing fuel savings in the commercial airline fleet, and for improving the competitive posture of U.S. transport aircraft in the world market.

This figure indicates that the load alleviation/extended span program has been highly successful, both in detail and in accomplishing the broad intent. The extended-span aircraft was committed to production while the research program was still under way.

QUESTIONS RESOLVED

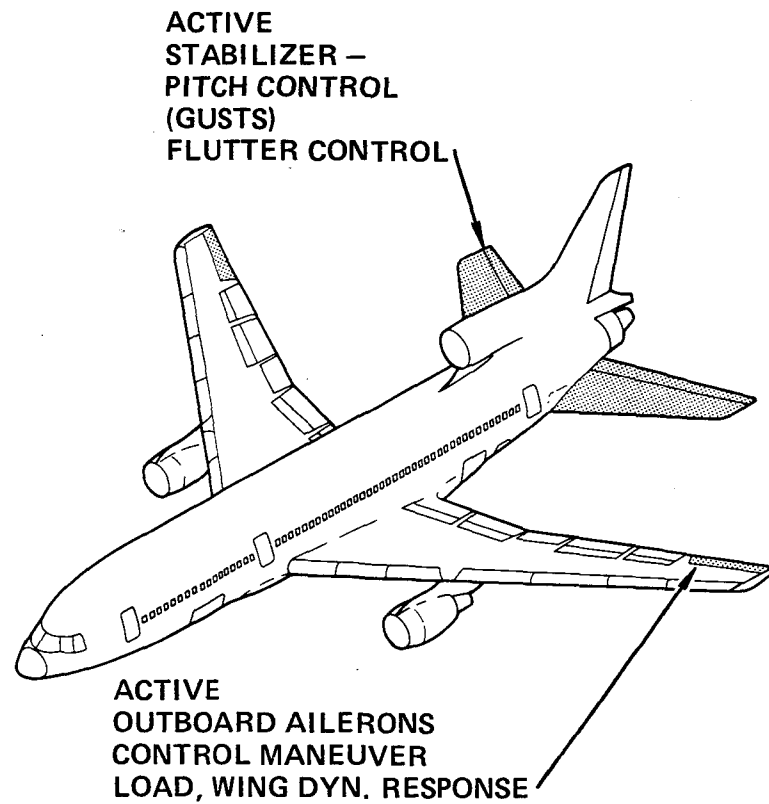
- ACTIVE CONTROLS FUNCTION AS PREDICTED
- DRAG REDUCTION PROVEN
- SYSTEM RELIABILITY OUTSTANDING
- FINAL SYSTEM SIMPLIFIED
 - ACTIVE STABILIZER FUNCTION NOT REQUIRED
 - ACTIVE FLUTTER SUPPRESSION NOT REQUIRED
- CUSTOMER DEMOS UNIFORMLY SUCCESSFUL
- UNBROKEN SUCCESSES ENCOURAGED EARLY MANAGEMENT COMMITMENT, SALES.

DEVELOPMENT CONFIGURATION/PRODUCTION CONFIGURATION

The research program resulted in a considerable simplification of the load alleviation system. It showed that the stabilizer function could be deleted — a considerable cost saving. Parallel Lockheed-funded tests showed that there was no need for a flutter margin augmentation function. These changes resulted in deletion of triple accelerometers in the two wing engines and of triple pitch rate gyros in the fuselage. The remaining sensors are triple accelerometers in each wing tip and in the fuselage, and triple impact pressure (speed) sensors for gain scheduling.

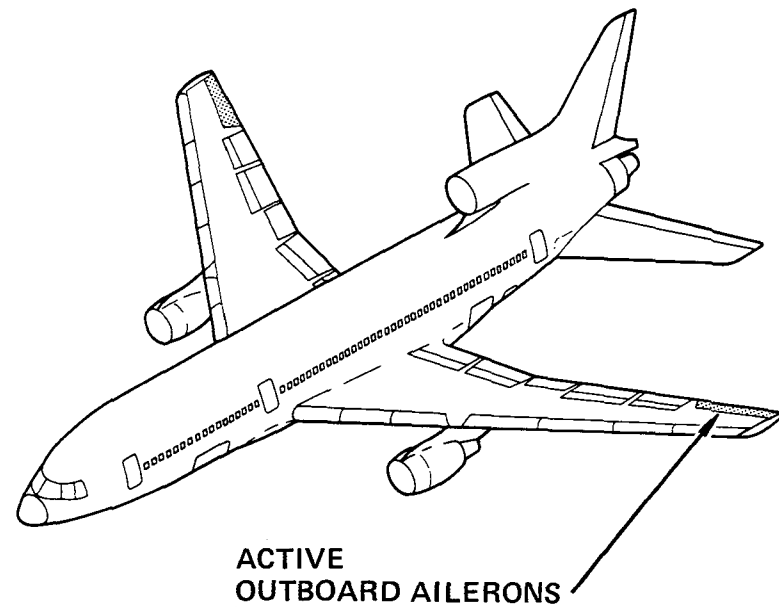
DEVELOPMENT CONFIGURATION

21 SENSORS



PRODUCTION CONFIGURATION

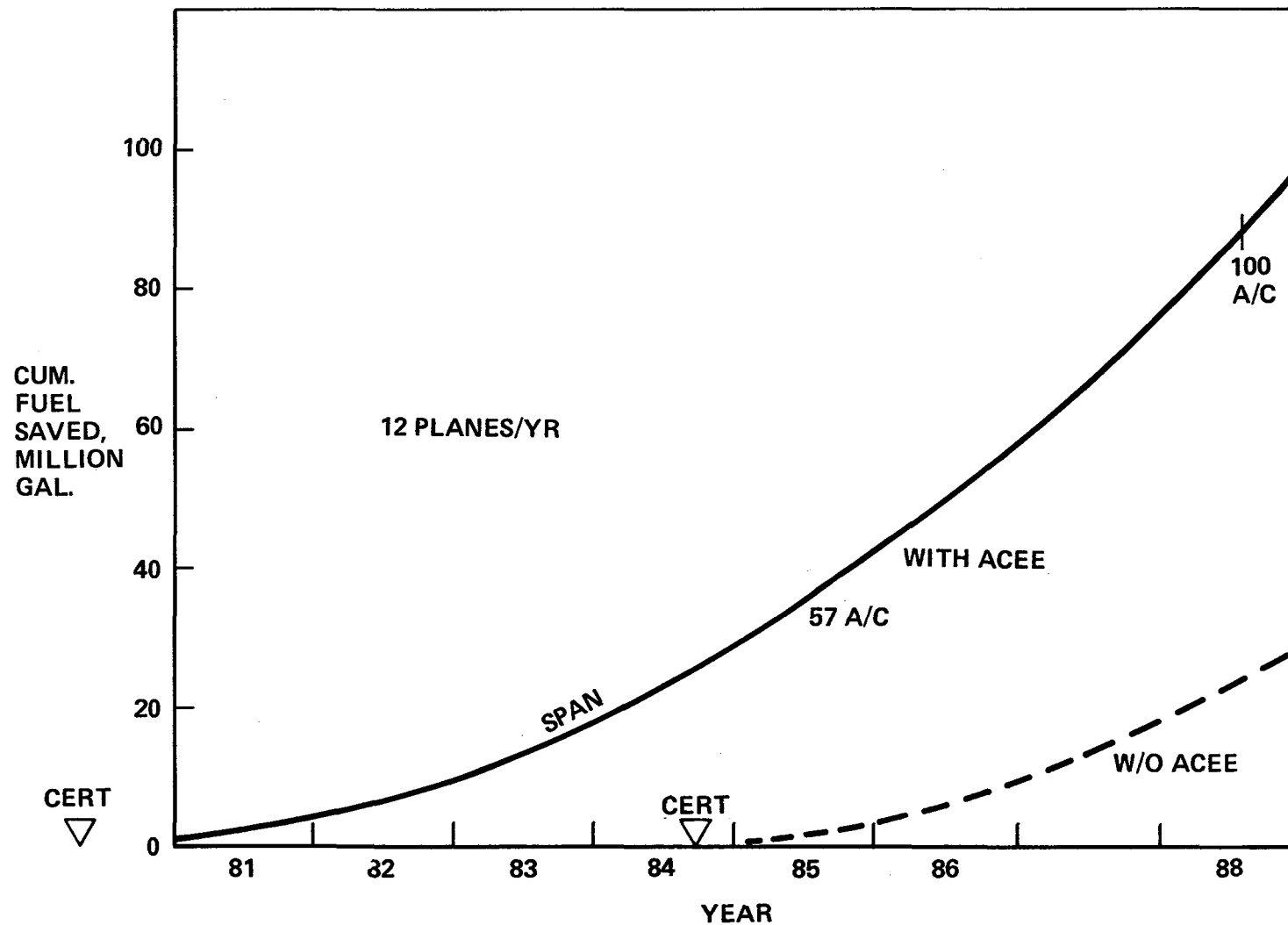
12 SENSORS



FUEL SAVING – EXTENDED SPAN

Each airplane with extended span will save over 200,000 gallons per year due to its 3% cruise drag reduction. This cumulative savings chart is constructed on the reasonable assumption that the NASA ACEE program accelerated the ongoing Lockheed active controls program by about 4 years, and on the relatively conservative assumption of a 12 planes/year production. With these data and assumptions, a cumulative fuel saving of 65,000,000 gallons will be realized by the end of 1988. This will increase (not shown here) to over 135,000,000 gallons in 1995, when the first aircraft is 15 years old.

FUEL SAVING - EXTENDED SPAN



TASK 2-AFT CG SIMULATION

TASK 2

Task 2 of the Lockheed Active Controls Study, Phase I, was devoted to developing background technological data for implementation of Relaxed Static Stability with Stability Augmentation on civil transport aircraft. The task objectives were to study the requirements and criteria in a generic sense and to provide design data for specific L-1011 derivative with a smaller horizontal tail.

The analysis and simulation have identified the critical flight regimes as cruise and approach. A simple, reliable lagged pitch damper was selected as a suitable augmentation system from candidate design concepts. Data for definition of system authority and reliability requirements were acquired. Equivalence to current aircraft handling qualities was confirmed as a useful criterion.

TASK 2

ANALYTICAL STUDY

- **CRITICAL REGIONS — CRUISE AND APPROACH**
- **AUGMENTATION DESIGN — DAMPER AND FEED FWD**
- **CRITERIA — EQUIVALENCE**

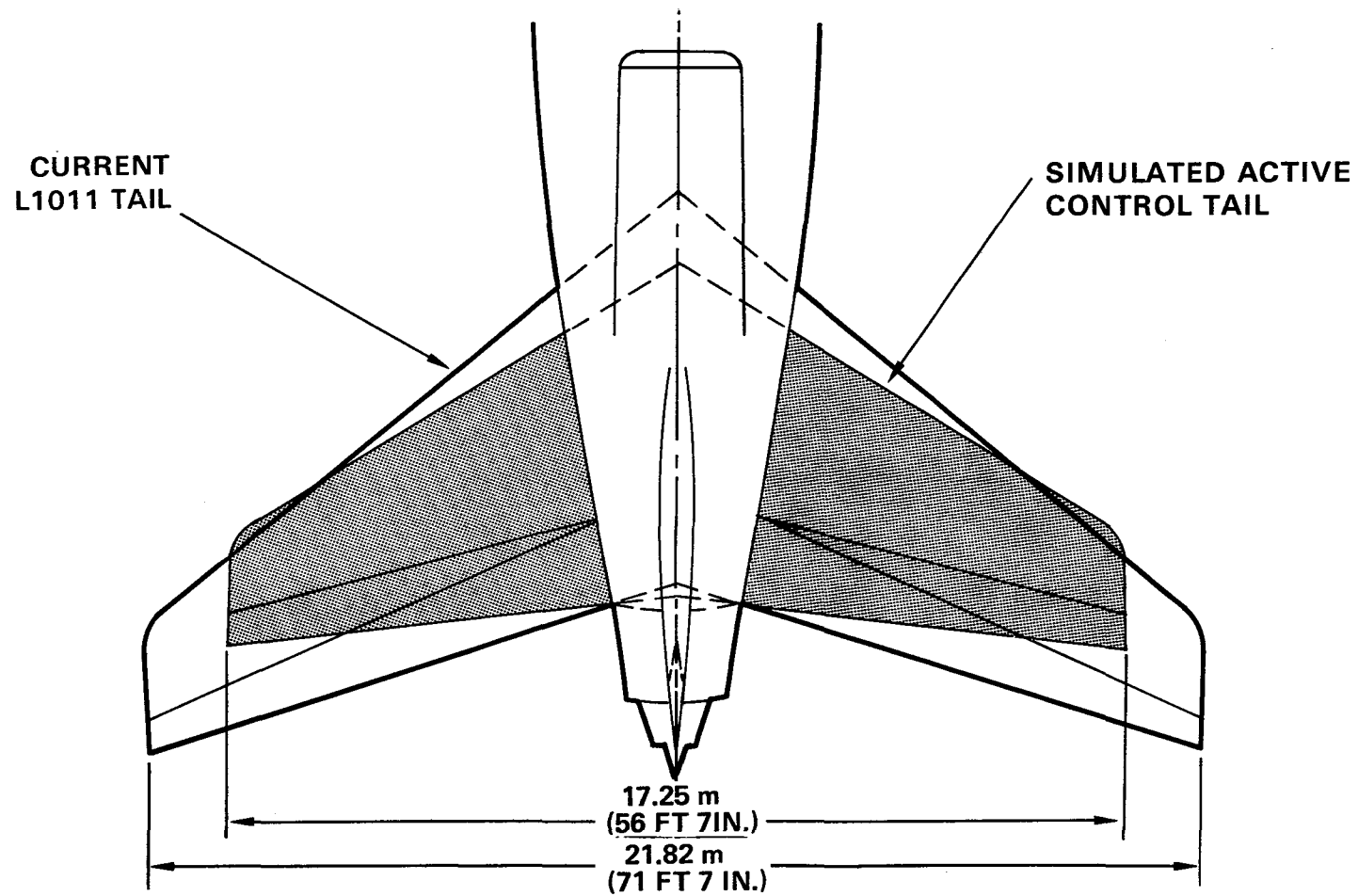
FLIGHT SIMULATION

- **AUGMENTATION EVALUATION — DAMPER**
- **UNAUGMENTED HANDLING QUALITIES — FAILURES**
- **SYSTEM REQUIREMENTS — AUTHORITY**

ACTIVE CONTROL TAIL PLANFORM

To provide adequate longitudinal control power with a smaller horizontal tail, an all new tail has been defined. The small tail airfoil section has been shaped to provide good high speed characteristics from a thick section with large leading edge radius. Hence, good low speed tail lift properties are attainable.

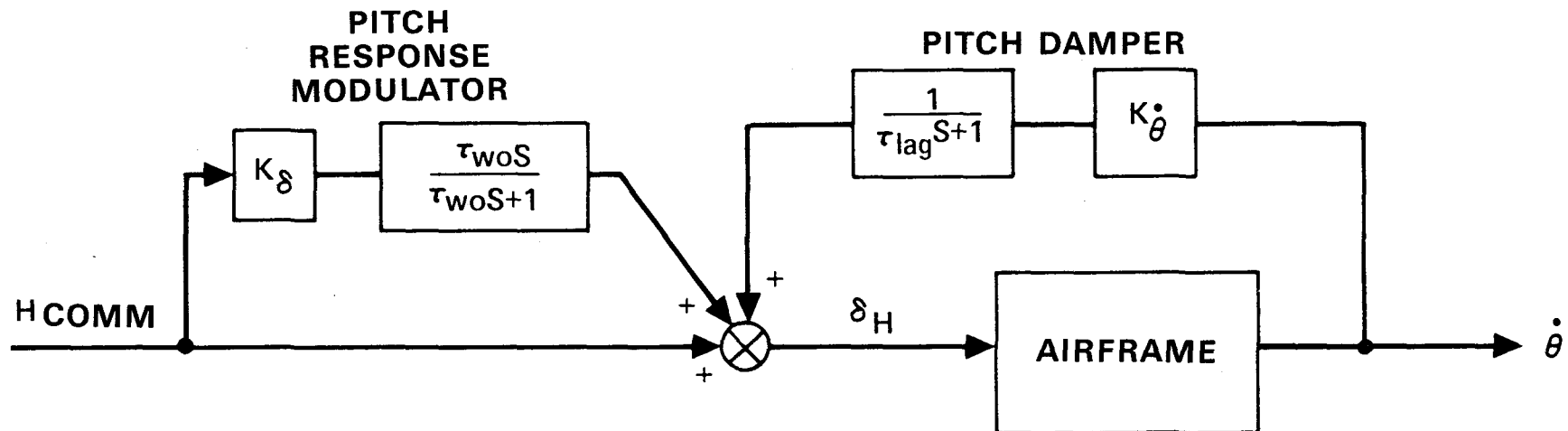
ACTIVE CONTROL TAIL PLANFORM



L-1011-AS AUGMENTATION SYSTEM BLOCK DIAGRAM

The L-1011-AS augmentation system is comprised of a lagged pitch rate damper with a feed forward loop for pitch response modulation and an axial acceleration feedback loop for speed control. The stabilizer feed-forward loop allows more flexibility in adjusting the pitch response.

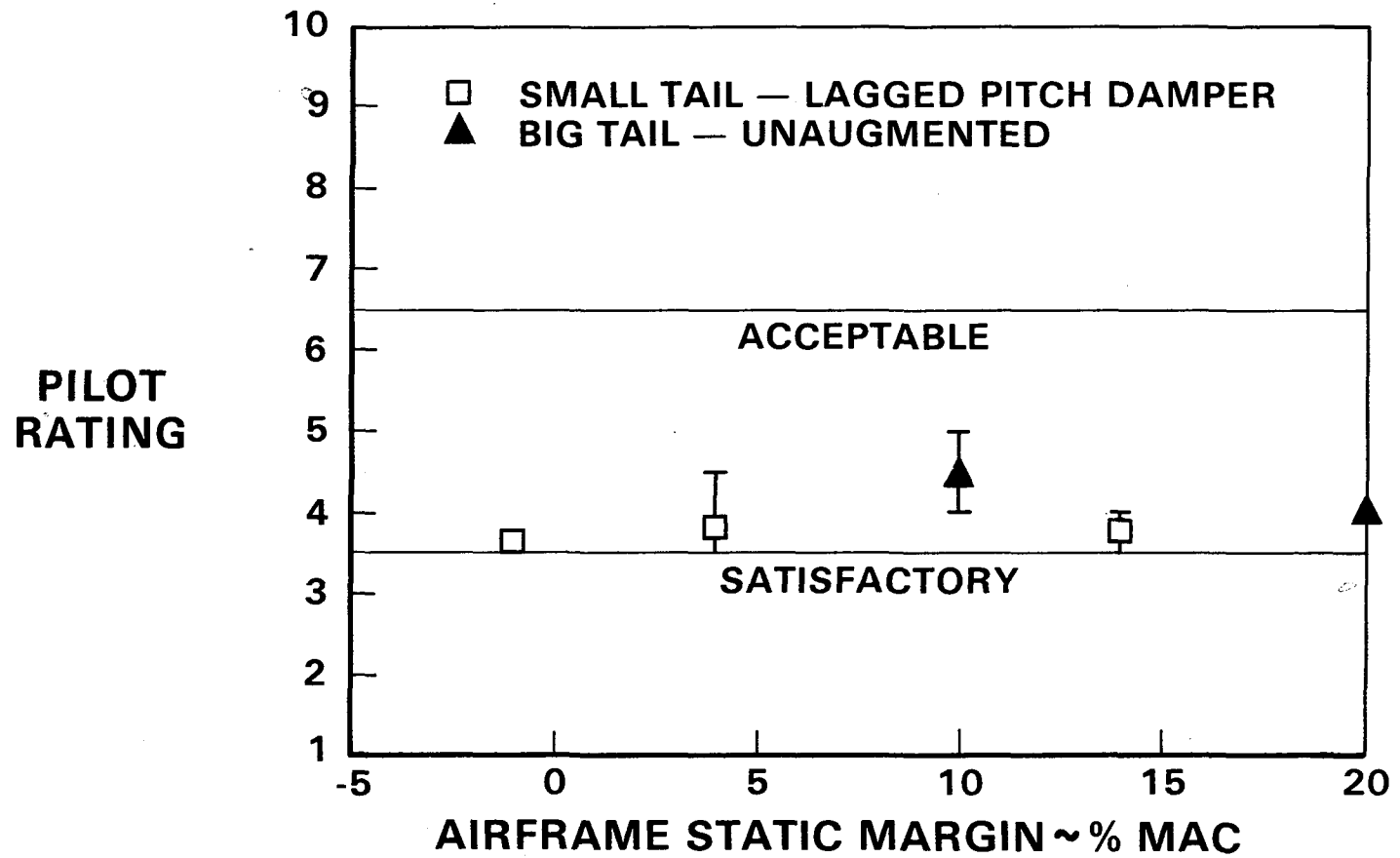
SIMULATION STUDY AUGMENTATION SYSTEM BLOCK DIAGRAM



CRUISE HANDLING QUALITIES IN HEAVY TURBULENCE

Performance of the pitch damper in heavy turbulence is sufficient to obtain nearly satisfactory ratings independent of airframe inherent stability down to at least neutral stability. The turbulence level simulated at cruise was 3.7 m/sec (12 fps) RMS. Ratings of the small tail airplane with augmentation were superior to those of the big tail reference airplane at equivalent static margin.

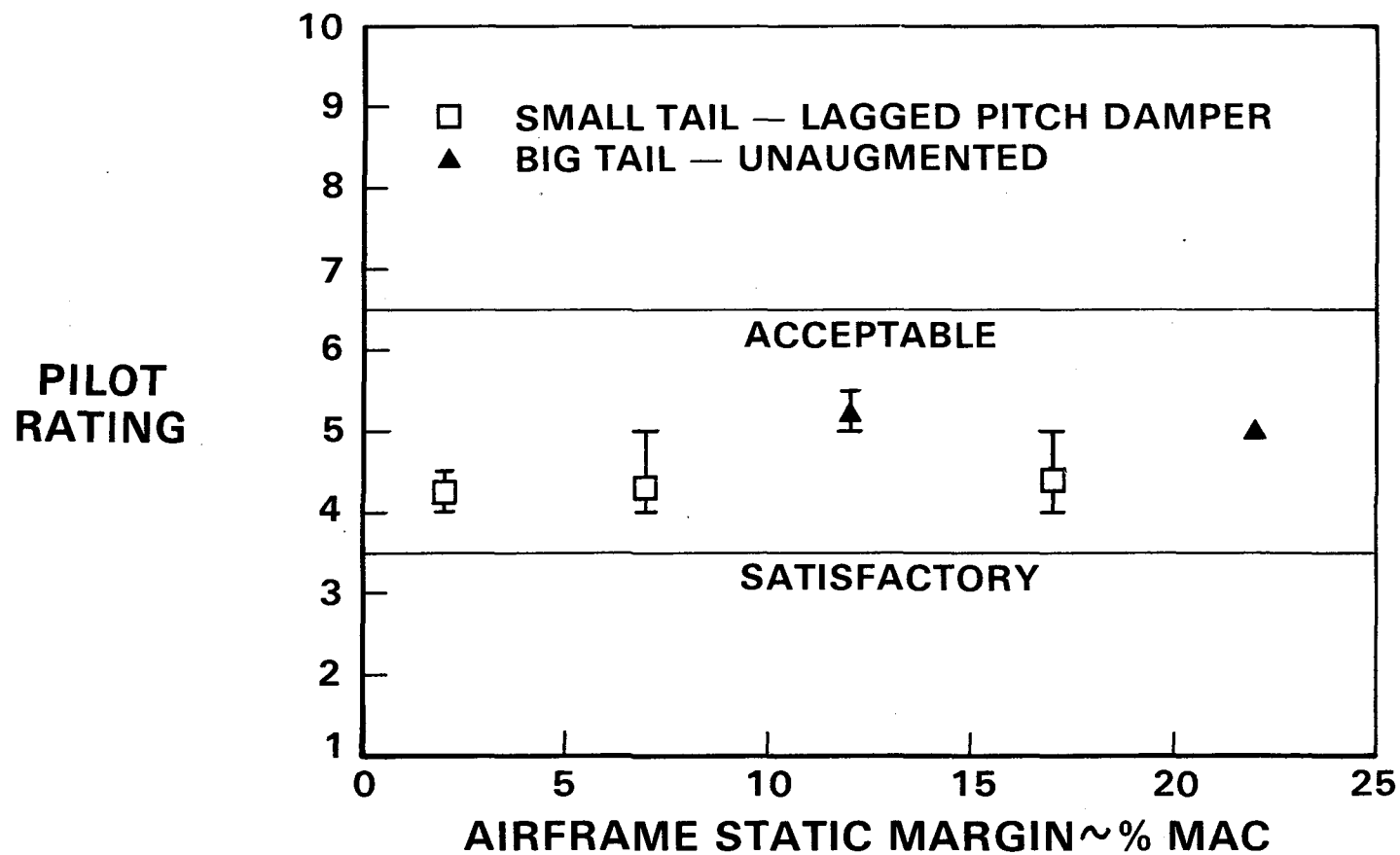
CRUISE HANDLING QUALITIES IN HEAVY TURBULENCE



APPROACH HANDLING QUALITIES IN HEAVY TURBULENCE

On landing approach the overall ratings in heavy turbulence became less satisfactory but still showed independence from static margin. Here the pilots indicated even greater preference for the small tail with augmentation.

APPROACH HANDLING QUALITIES IN HEAVY TURBULENCE

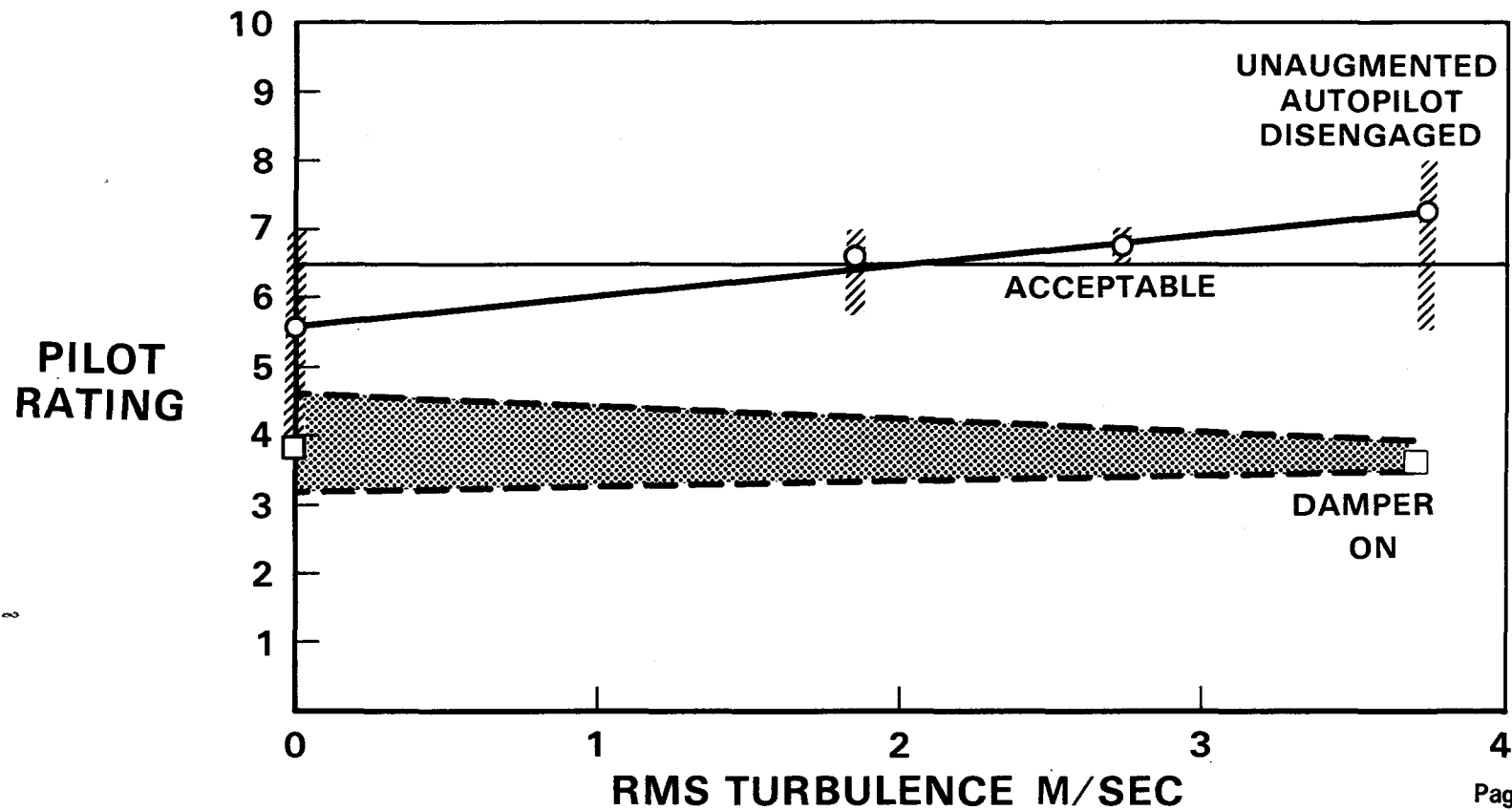


CRUISE HANDLING QUALITIES DEGRADATION NEUTRALLY STABLE AIRFRAME

In the event of a total failure of the redundant stability augmentation systems and with no assistance from the autopilot, handling qualities of a neutrally stable transport would be degraded. The degree of loss in acceptability is a function of air turbulence level. At a RMS random turbulence scaling velocity of 2m/sec (approximately 6 fps) the pilot ratings in the cruise condition become marginally acceptable.

Dashed lines for the damper on data and shaded strips for unaugmented indicate the scatter band of the ratings from the flight simulation study.

CRUISE HANDLING QUALITIES DEGRADATION NEUTRALLY STABLE AIRFRAME

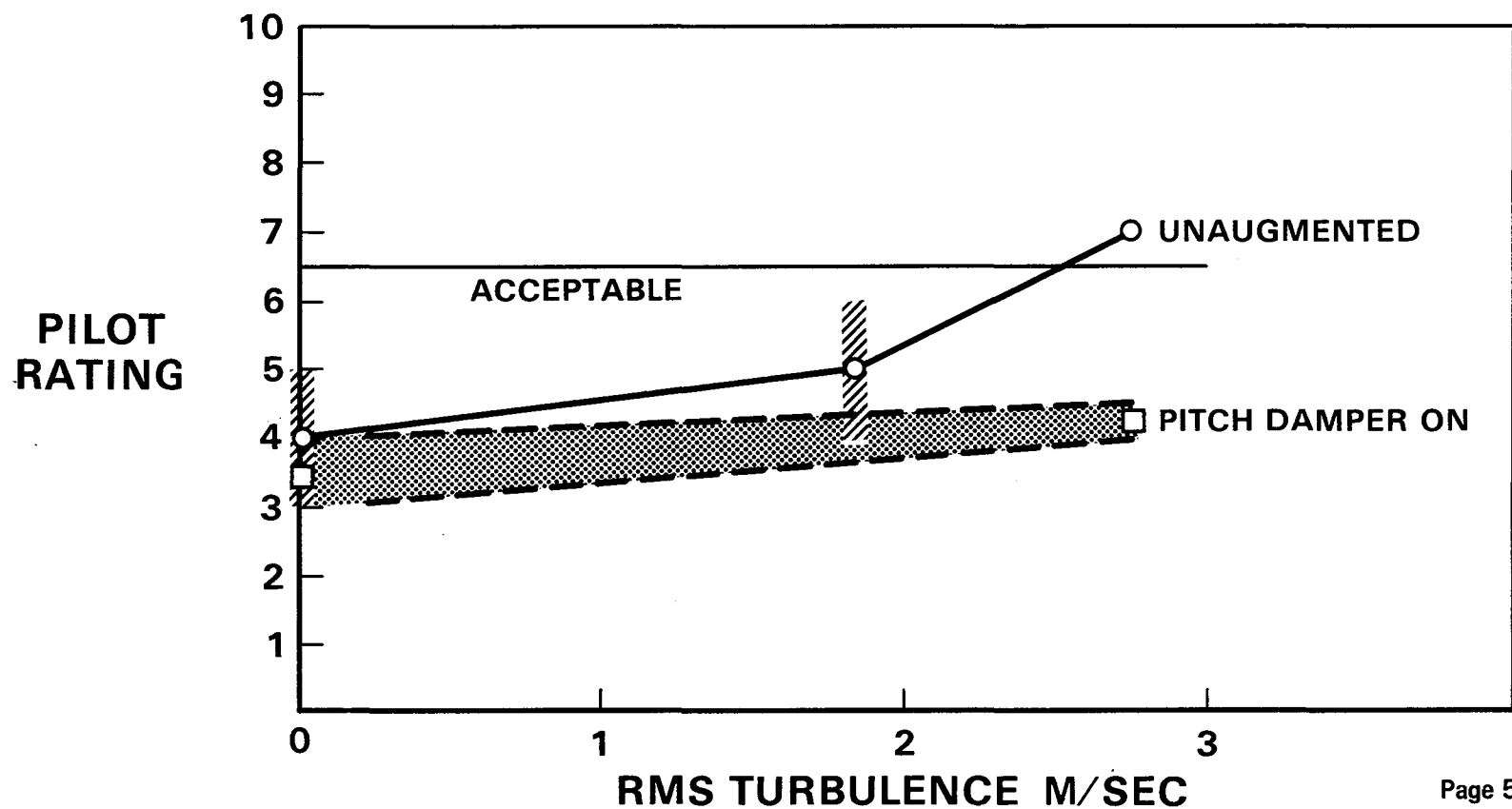


APPROACH HANDLING QUALITIES DEGRADATION NEUTRALLY STABLE AIRFRAME

At the approach condition, loss of augmentation in calm air produces little degradation of pilot opinion rating. Not until turbulence RMS velocity exceeds 2.5 m/sec (nearly 9 fps) does the overall rating become unacceptable.

Augmentation system availability requirements must be defined by combined probability analysis taking into account the system performance, component reliability and turbulence exceedance probability function on a mission analysis basis.

APPROACH HANDLING QUALITIES DEGRADATION NEUTRALLY STABLE AIRFRAME

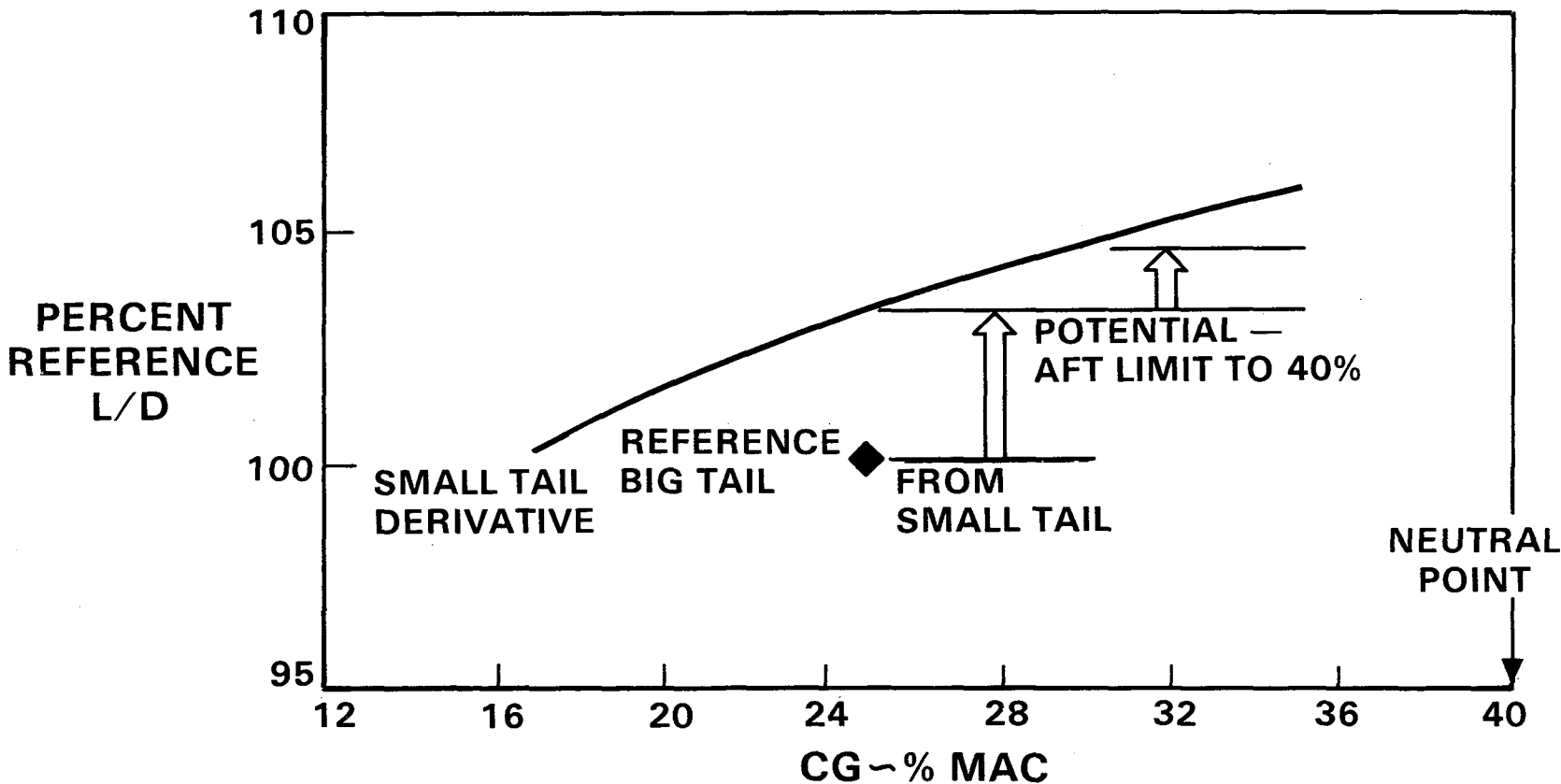


RELAXED STABILITY BENEFIT FROM NEAR TERM DERIVATIVE

Fuel efficiency benefits from augmented relaxed stability for L-1011 derivatives come from two sources. The smaller tail contributes 3 percent improvement in cruise L/D due primarily to reduced parasite drag. Further improvement of 1.5 percent is available from balance changes which move the cg aft limit back 5 percent from the present location.

Both benefits are attainable with current augmentation technology as demonstrated by the simulation study.

RELAXED STABILITY BENEFIT FOR NEAR TERM DERIVATIVE

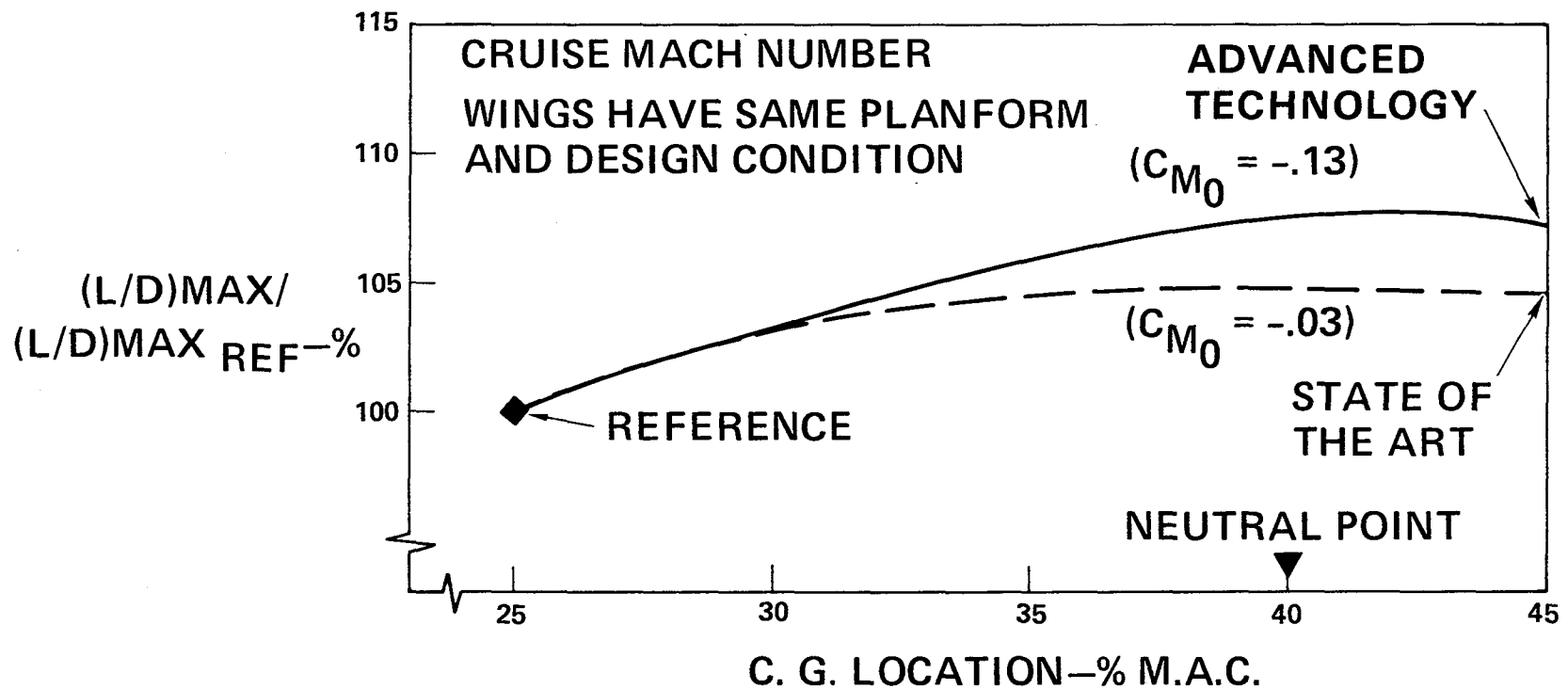


RELAXED STABILITY BENEFIT FOR ADVANCED TECHNOLOGY WING

Significant improvement in cruise aerodynamic efficiency is available from advanced technology wings. However, due to the more aft center of pressure characteristic of advanced airfoil sections, the benefits are lost to trim drag unless the center of gravity is moved aft. To take full advantage of the benefits available from a new generation of wings, airplane center of gravity limits must be located about 20 percent farther aft on the mean aerodynamic chord than it is on current transports. This results in airframes which may be 10 percent to 15 percent statically unstable at aft cg.

Augmentation system performance and reliability must exceed those of current active controls systems. Development of advanced controls should proceed concurrently with wing development for far term applications.

RELAXED STABILITY BENEFIT FOR ADVANCED TECHNOLOGY WING



CONCLUSIONS

ACTIVE CONTROLS/LOAD ALLEVIATION

- **TECHNIQUES & APPLICATIONS PROVEN**
- **INTEGRAL PART OF L-1011-500-3% FUEL SAVING**
- **ENTERS AIRLINE SERVICE-SPRING 1980**

ACTIVE CONTROLS/AUGMENTED STABILITY

- **CRITERIA SET FOR TODAY'S SYSTEMS**
- **FLIGHT APPLICATION STARTING-ACEE/EET PHASE II**
- **ADDITIONAL 3% FUEL SAVINGS WITH TODAY'S SYSTEMS**
- **MORE BENEFITS WITH HIGHLY RELIABLE SYSTEMS**

REFERENCES

1. Flapper, J.A., and Throndsen, E.O.: L-1011 Flight Control System. AGARDograph AGARD-AG-224, April 1977.
2. Hoblit, F.M.: Effect of Yaw Damper on Lateral Gust Loads in Design of the L-1011 Transport. Presented at 37th Meeting of the AGARD Structures and Materials Panel, The Hague, Netherlands, 7-12 October 1973.
3. Povinelli, F.P., Klineberg, J.M., and Kramer, J.J.: Improving Aircraft Energy Efficiency. AIAA Astronautics and Aeronautics, pgs. 18-31, February 1976.
4. Leonard, R.W., and Wagner, R.D.: Airframe Technology for Energy Efficient Transport Aircraft. SAE 1976 Transactions, Section 4, pgs. 2916-2931, September 23, 1977.

LIBRARY MATERIAL SLIP DO NOT REMOVE SLIP FROM MATERIAL Delete your name from this slip when returning material to the library.		
NAME	DATE	MS
R.G. Kadernik	12/02	340